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Integrating Capital Cost with Energy Efficiency – Cost@Work

ABSTRACT

It has always been a perception that implementing energy efficiency in buildings increases capital cost for developers. Passive features such as additional roof insulation, wall insulation, high performance glazing, daylight harvesting and etc. increases capital cost in new buildings. Active features such as variable flow, radiant cooling system, desiccant dehumidification and etc. are also seen as additional cost to developers. Compounding on to this perception is that the architects and engineers often works independently of one another, with each party often ignoring the benefits implemented by the other party.

A software was developed to integrate both the passive and active features within a simple shoe-box building scenario to provide peak cooling load computation, annual energy consumption prediction, while computing the building material/equipment capital cost at the same time. The most interesting part of this software is its ability to automatically run through a database of building material and equipment to calculate the building energy consumption and peak load of each combination. It then hunts for the lowest capital cost and/or lowest lifecycle cost of the project by calculating the combined capital cost for each of the tested combination of building material, equipment and air-conditioning selection.

A version of this software is in operation since early 2016 and has been providing indications that that in almost all cases, energy efficiency in building can be improved while reducing capital cost. In fact, capital cost reduction up to 7% of total building construction cost has been regularly demonstrated with this software, while at the same time improving energy efficiency in building.

The output from this software is a clear demonstration that a truly integrated design strategy that combines passive, active and costing features within a single platform will yield better energy efficiency at a lower capital cost for the building industry.

Keywords: Building energy simulation; Lifecycle assessment; Energy saving

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1. INTRODUCTION

There exist many buildings today that are claimed, designed to be energy efficient. However, it is still very much a market perception today that an energy efficient building is more expensive to build. One of the early successful demonstration of low energy office building in Malaysia was even documented, in 2005, to have an additional cost of 10% above the base total building construction cost [1].

Additional cost in an energy efficient building is largely fuelled by the increased complexities of air-conditioning equipment and better building fabric on a building. Examples of such items are:

- Variable air volume instead of constant air volume
- Variable speed chiller instead of conventional chiller
- More efficient lighting system instead of conventional light
- High performance double glazing with low emissivity instead of typical single glazing
- Increased building fabric insulation
- And more.

However, improving energy efficiency also reduces the building cooling load. A reduction in cooling load reduces the capacity (size) of air-conditioning system for a building. This lead to a reduction in capital cost. Unfortunately, there is hardly any actual case study of the actual amount of capital cost reduction due to implementation of energy efficiency in building. This leads to the perception that energy efficiency in building is expensive.

A software, Cost@Work, was developed recently that is able to address this missing link between energy efficiency and capital cost. This software is currently based on Malaysian climatic conditions and building construction practices. The software computes both capital cost and running cost instantly based on a shoe-box model allowing important decision related to energy efficiency and capital cost to be made instantly. These information, provided upfront, allows the design team to set the design direction of a building at the onset of the design stage, to optimize both capital and running cost of a building.

Finally, the benefit in being able to demonstrate a reduction in capital cost while implementing energy efficiency is immense in the engaging developers to consider sustainability in all buildings.

2. ENERGY EFFICIENCY IS COMPLEX

Energy efficiency in building design involves the selection of building fabric, lighting system, air-conditioning system, operational practices, passive cooling strategy and more. And within each major element, there are even more elements that can to be optimized. For example, a building fabric will need to optimize its insulation, thermal mass, solar absorption, emissivity, shading (as in a double roof) and more. There are at least hundreds, if not thousands of opportunities for energy efficiency in a building. Due to the near limitless possibilities of energy efficiency in buildings, the task of finding the least cost and/or best lifecycle method of addressing and optimizing energy efficiency in a building is not simple.

3. ENERGY EFFICIENCY AND COOLING LOAD

An energy efficient building is often the combinations of many energy efficiency features that is implemented on a building. The Passive and Active Design Guideline provided by the Building Sector Energy Efficiency Project (BSEEP) has shown that most energy efficiency feature provides an improvement in energy efficiency in a building by an average of 1% in Malaysian conditions. The impact on peak cooling load is even less per feature wise. An energy efficiency case study made for a high-rise office tower in Malaysia showed a possibility of reducing building energy consumption over 60% with the implementation of approximately 50 energy efficiency features in the building. However, the peak cooling load reduction is only 30% [3]. This indicates that on average the peak cooling load reduction is less than 1% per implemented energy efficiency feature.

Due to this, many (if not all) air-conditioning engineers have subliminally learned that impact of a single element or product on the cooling load is marginal at best, and therefore are always reluctant to reduce the initial design capacity of the air-conditioning system. Unintentionally, many existing energy efficient buildings have an oversized cooling system installed.

4. BUDGETING OF CAPITAL COST

Budgeting of capital cost in the development of Malaysian buildings are split into 2 categories; the building cost and; the mechanical and electrical equipment cost.

A quantity surveyor will estimate the building cost based on the architectural and structural engineer’s drawings and specifications; while the mechanical and electrical equipment cost are estimated by the appointed trade engineering consultant. These parties often do not communicate with one another well enough. Products such as roof and wall insulation; and better glazing properties that are specified by architects and quantity surveyors are often not considered by the air-conditioning engineers.

However, these items have an influence on a building peak cooling load. And the peak cooling load of a building is the key determination of the air-conditioning equipment cost. The larger the capacity, the higher the cost will be. With the average installed cost of air-conditioning system today ranging between 10% and 20% of a building total construction cost, air-conditioning represents one of the highest single element cost in a building construction [4].

5. LACK OF COMMUNICATIONS

Building construction is a very complex process. It involves many parties because it is impossible for any one party to be able to design every part of a building. Over the years, the building industry has fine-tuned this process into a very lean linear system of communication between the different parties.

Putting it simply, the architect provides the drawings and specifications; and the design engineers size the necessary equipment for the building, with very little integrated design opportunity.

Most architects have little knowledge of an air-conditioning system. They have little understanding of the building fabric impact on the air-conditioning load, capital cost and running cost. However, they are the primary decision maker in charge of specifying building fabric. Meanwhile, most air-conditioning engineers have little to no interest in building fabrics, leaving the selection entirely to the architects.

6. BUILDING ENERGY SIMULATION

Building energy simulation studies have often been touted as the solution to the issues raised. Energy simulation enable studies to be made, to optimize building design on energy efficiency and cooling load. However, there are 2 major barriers that needs to be overcome for this solution to work in practice:

- Building simulation studies are complicated.
- Capital cost has not been made as part and parcel of building analysis.

6.1. Complexities in Building Energy Simulation

Building energy simulation study is a fairly complex matter. Even with the most user friendly software in the market today, efforts are required to ensure that the defaulted values and assumptions made by the software matches with the conditions of the building and site location. This is not often the case. All of these software defaulted the values and assumptions based on the standard of practice of their primary market, such as US, UK or Europe. Buildings in other location requires significant changes to the defaulted values. It often takes up to several weeks of intensive work to ensure that the building was even modelled correctly.

Getting a building modelled correctly is not a simple process at all. A 3D model of a building is only the beginning of energy studies in a building. Information is also required on the details of the building envelope for each wall, glazing and roof; occupant’s load and profile; equipment’s load and profile; lighting load and profile; type of air-conditioning system used; climatic data; phantom load assumption, elevators and controls power consumption; ventilation in car park; ventilation in toilet; outdoor air quantity; infiltration assumption and more.

Sometime, part of basement wall is buried under the earth, part of it not. Part of the building is naturally ventilated and part of it is not. Part of a floor may be directly connected to the earth, while part of it is exposed to outdoor air. Standards on construction for walls, roof and glazing is also different from country to country. Thermal breaks requirements are different depending on the climate. Typical working hours, operational practices on lighting, air-conditioning and type of system available is also different based on site location. In short, there are thousands of numbers that need to be reviewed for each simulation study.

Furthermore, a good building energy simulation analysis requires knowledge of multiple trades. For example, a building energy simulation practitioner need to know the different types of building fabrics that is available in the market for wall, roof and glazing. This person also has to understand the properties of insulation, solar absorption, emissivity and more to be able to give good advice to a project. Information provided by manufacturer datasheet can sometimes be wrong or have units mislabeled. There is also a need to understand outdoor air requirement for each spaces and infiltration possibilities based on the construction practices at that location. There is also a need to know about the availability of various types of lighting system based on the building location.

Finally, an air-conditioning system is an extremely complex beast even for an experienced engineer. For example, the available fan and motor efficiency is different for different types of fan and flow rate. The total pressure drop of a fan is different for different types of cooling coil, air filter, distance of duct, duct size and more. Performance of a chiller efficiency at peak and part load is strongly dependent on the selected capacity of the chiller. Small chiller typically has lower efficiency than larger chiller. Cooling tower optimization of control is different for different wet bulb condition at different location. Even developers of energy simulation software themselves do not have full understanding of the intricacies of each and every equipment. And yet there is a very unrealistic expectation in the building industry that any building architect and engineer can conduct building energy simulation studies accurately for any building in this world with the use of such complicated tool.

6.2. Lack of Integration of Capital Cost within Energy Simulation

There is hardly any building energy simulation tool today that integrates capital cost into building energy simulation studies. This is a drastic loss of opportunity for these software to provide quick answers to the most important question for a building developer – which building product or strategy of operation will yield the best return on investment on this development?

Typically, the person conducting the simulation study provides the results for different options of design; other trades are than required to provide the costing on these options. This process often takes up several weeks to arrive at the final answer. The long duration of such a process poses a major limit on the number of studies that can be carried out.

7. COST@WORK

Initial version of Cost@Work was a tool called BEET, short for Building Energy Estimation Tool. It was developed in 2005 in Excel, to allow general building design practitioner an easy method to estimate building energy consumption with minimum inputs. The simplicity of input on this software encouraged the tool to be adopted by Association of Consulting Engineers Malaysia (ACEM) for Malaysian building industry. By entering easily understood data into approximately 50 cells, the software is able to make a general estimate of the yearly energy consumption for a building in Malaysia.

The annual cooling load of a building was computed using the definition of Overall Thermal Transmission Value (OTTV). The OTTV is a familiar term in South East Asia and is used by Malaysian Standard, MS 1525, since 1990s. It provides a manual method of calculating the average thermal transmission value through a building fabric over a period of a year. The original form of OTTV was developed for ASHRAE Standard 90 in 1975 and was refined again in 1980 [6][7].

An enhancement of BEET was performed in 2015 under Building Sector Energy Efficiency Project (BSEEP) in Malaysia. A stakeholder consultation was made with the building industry practitioners to seek feedback on how the new software should work. Feedback received was to make the software ‘idiot proof’ rather than enhancing the software computational features. It was highlighted that many architects and engineers do not know the correct value to enter into the software such as U-values, shading coefficient, fan efficiencies, fan total pressure, system coefficient of performance and etc. [5]

Based on the feedback received, BEET made changes to the cooling load computation method to Ashrae Radiant Time Series Method (RTSM). The use of RTSM, allowed the software to estimate the peak and average cooling load of a building instead of just the average cooling as provided by the older version. The peak cooling load allowed an early estimation to be made by the software on the type of fan, pumps and chillers that may to be used without any the need of an expert to provide input. This prevented users from entering values that are not realistic into the analysis. In addition, input data for all technical inputs were fixed to a pull down menu to select the types of wall, glazing, roof, lighting system and etc. using well-known generic terms that is easily recognized in the building industry. Most of the pull down menu was provided based on the selection of 4 options; inefficient, typical, efficient and very efficient scenarios. These features limit the potential error a person can make by ensure that all values entered are within reasonable range, thereby, ‘idiot proofing’ the software.

In 2016, BEET version 2 was developed into Cost@Work with the primary objective of optimizing building design based on capital cost, running cost, payback period, return in investment and lifecycle analysis. A product cost database of building material, lighting and air-conditioning was added into the software. With the inbuilt cost database, Cost@Work able to run a subroutine to test each and every design option that is available in the software to provide an estimate on net capital cost and running cost of it. A net capital cost refers to the total cost of air-conditioning system together with the building material or product selected.

The software is able to compares all options of wall, glazing, roof and etc. that is available in the database. For each element type in the database, it computes the total element capital cost, building running cost and cooling equipment cost (from the peak cooling load). The net total capital cost of the element with the cooling equipment are then analysed together to find the best design option for the building and at the same time computing the running cost.

For example, it may compute that the use of a 100mm thick concrete wall will cost the building RM 300k for the wall and RM 17.5 million for the air-conditioning system. An insulated wall option will cost the building RM 900k for the wall and RM 16.6 million for the air-conditioning system. Analyzed individually the additional cost for an insulated wall is 300%, while the air-conditioning cost was reduced by 5%. However, when these numbers are analyzed together in absolute values, the insulated wall reduces the capital cost of the building by RM 300k, while improving energy efficiency at the same time.

This analysis is conducted for the entire database of building envelope and lighting system within minutes by the software, providing a roadmap of design options for the lowest capital cost, highest energy saving and lifecycle analysis of 5, 10 and 20 years.

In short, Cost@Work is able to provide instant documentation with engineering calculation that it is possible to improve energy efficiency in building while reducing capital cost at the same time. It provides an output that is easily understood by the building investors that are focused at their rate of return on investment.

8. VERIFICATION

While, the financial computation in Cost@Work is easily verified using a manual calculator, the verification of the software is required on its cooling load computation engine that was based on Ashrae Radiant Time Series Method.

A verification work was conducted under BSEEP project using IES<VE> and BEET version 2 software, which Cost@Work was developed from. The verification procedure follows similar methodology as Ashrae Bestest 140: Test Procedures "Building Energy Simulation" Tools, where a range of identical design options were tested on both software and its results compared with one another.

The verification study compares the predicted Building Energy Intensity (BEI), building yearly energy consumption in kWh/(m².year) and peak cooling load in kW of cooling power. Results of the study showed good agreement between the 2 software as shown in Figure 1 below. A detailed report on the verification study can be found within the BSEEP project [8].

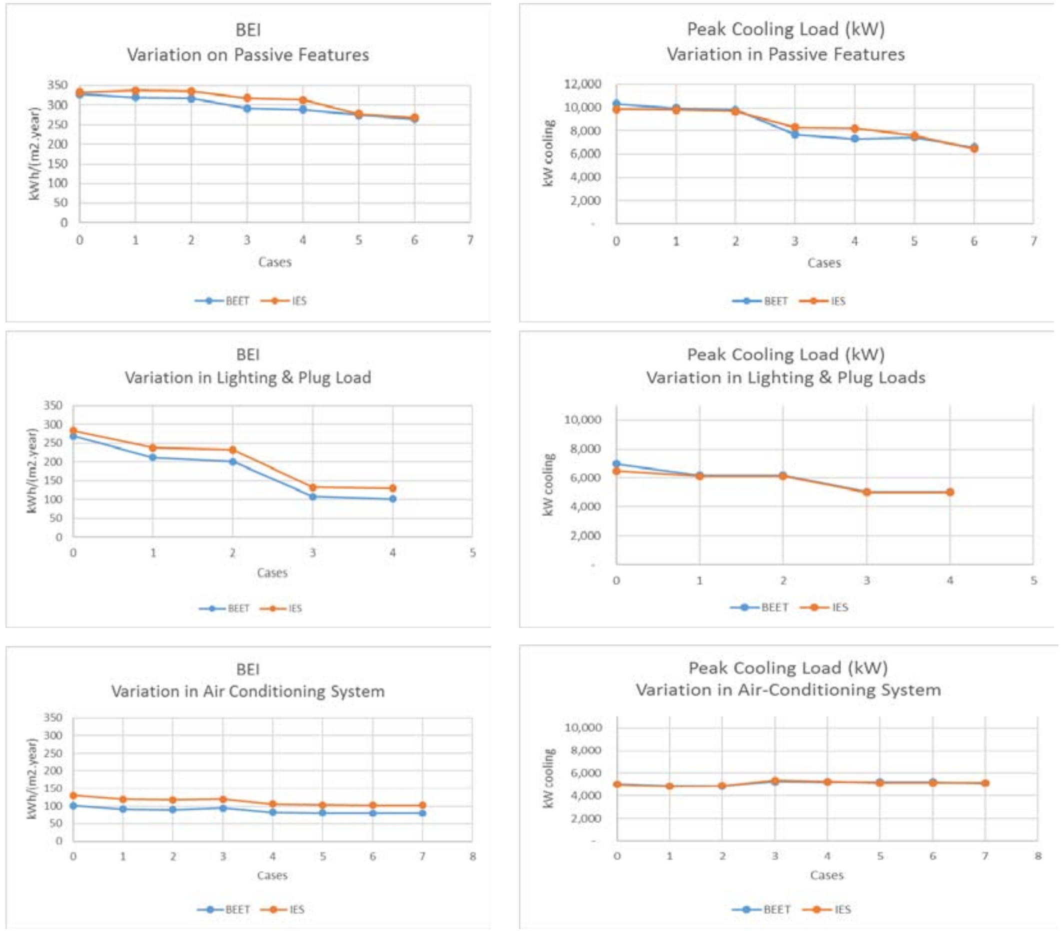

Figure 1 Verification Results between IES<VE> and BEET

9. SUMMARY

Cost@Work was deliberately made simple for quick initial analysis to be conducted easily at an onset of building design development while minimizing the risk of errors in data entry. It gives immediate computation of the estimated running cost, peak cooling load and capital cost of building elements and air-conditioning system. This allowed the software to provide immediate comparison of payback, rate of return and lifecycle analysis of various design options in a building.

In addition, the language of the software was kept simple and easily recognizable by building design practitioners. This will encourage better communication between the different trade discipline, allowing consultants to understand each other easily.

As a pre-design tool, the accuracy provided by Cost@Work is more than adequate for key decision to be made early on in the design process to optimize a building capital cost and energy efficiency.

Finally, such a software encourages the building industry to pursue energy efficiency in buildings, as it can now be proven from the earliest stage of design that energy efficiency is capable of reducing capital cost when it is done right.

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